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Performance Enhancement of DWDM Systems Using HTE Configuration for 1479-1555nm Wavelength Range

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Abstract**—**In this paper, the gain spectrum of EDFA has been broadened by implementing HTE configuration for S and C band. On using this configuration an amplification bandwidth of 76nm ranging from 1479nm to 1555nm with a peak gain of 26dB has been obtained.

Keywords**—**C band, DWDM system, EDFA, Gain, HTE, Hybrid Fiber Amplifier, S band.

I. Introduction

THE optical fiber can be doped with any of the rare earth element, such as Erbium (Er), Ytterbium (Yb), Neodymium (Nd) or Praseodymium (Pr). The host fiber material can be either standard silica, a fluoride based glass or a multicomponent glass. The operating regions of these devices depend on the host material and the doping elements. Fluorozirconate glasses doped with Pr or Nd are used for operation in the 1300nm window, since neither of the ions can amplify 1300nm signals when embedded in silica glass. The most popular material for long haul telecommunication applications is a silica fiber doped with Erbium, which is known as EDFA [1]-[5]. In some cases as Yb is added to increase the pumping efficiency and the amplifier gain. The operation of EDFA by itself normally is limited to the 1530-1560nm region. EDFA has a narrow but high gain peak at 1532nm and at 1550nm a broad peak with a lower gain is observed. In order to take the advantage of the whole amplification band provided by EDFA gain spectrum, filtering or equalization techniques have to be applied. It is a well known fact that the EDFA requires lesser power for the pump source and these pump power requirements can easily met by laser diodes. Hybrid fiber amplifiers with different gain bandwidths are the key components for the Dense Wavelength Division Multiplexed systems in C-band and L-band. For taking the benefits of whole amplification bandwidth of hybrid amplifiers, the broadening as well as flattening of gain spectrum of EDFA is preferably required. There are different ways to increase the gain bandwidth of optical amplifiers [6]-[16]. The broadened and flattened spectrum will allow enough number of multiplexed channels to be amplified which is the basic need of DWDM systems. In today's technological era, TDFA offers more advantages over EDFA such as low absorption loss due to OH- ions, low fiber loss and low dispersion. In order to overcome the increasing demand of information traffic in DWDM communication systems, it is primarily required to increase the wavelength range of telecommunication. This means it is the time to explore optical amplifiers in the S-band along with already existing optical amplifier i.e. EDFA in the C-Band and L-Band. One of the feasible answers for utilizing S-Band is Thulium Doped Fiber Amplifier. TDFA is a fiber doped amplifier which uses thulium as dopant and works on the principle of stimulated emission using thulium. An Emission occurs at 1.47µm between the two excited levels 3H4 and 3F4 [17], [18]. This emission exactly matches the range of S-Band. So, with TDFA high gain, high efficiency and low noise can be achieved [19], [20]. However, the energy level structure of thulium (Tm+3) leads to many important differences in comparison with its erbium counterpart. Tm+3 produces stimulated emission from a transition that terminates above the ground state. This makes Tm+3 inherently less efficient, so optimizing the pump source and glass host is particularly important. The properties of Tm+3 lead to silica being a poor host material for optical amplification. Despite of these complicated properties amplification has been observed in the S-band region of the 3rd telecommunication window.

II. Methodology Followed

The three level energy diagram of EDFA in which the signal gain is achieved by a metastable population of excited ions by emission decay from a higher pumped state is considered in the proposed model. In this section modeling of EDFA has been proposed using improved rate equations of a three state EDFA by considering forward ASE. Fig. 1 describes three level energy diagram of EDFA with various energy transitions. The three population states of Er+3 are ground state (g) with population density of ng, the metastable state (m) with population density of nm which is related with signal frequency and excited state (e) population density of ne which is related with pump frequency.

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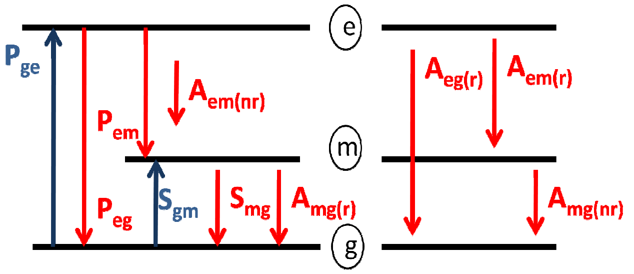

Fig. 1 Three level energy diagram of EDFA

So, the improved rate equations of the three states for the proposed model are given in (1):

$$\frac{\delta n_g}{\delta t} = \left(-P_{ge}\ n_g\ - S_{gm}\ n_g\ + S_{mg}\ n_m + \frac{n_m}{\tau} + P_{eg}n_e\ + \frac{n_e}{\tau'}\right)$$

$$\frac{\delta n_m}{\delta t} = \left(S_{gm}\ n_g\ - S_{mg}\ n_m - \frac{n_m}{\tau} + P_{em}n_e\right)$$

$$\frac{\delta n_e}{\delta t} = \left(P_{ge}\ n_g\ - P_{em}\ n_e - P_{eg}n_e - \frac{n_e}{\tau'}\right) \quad (1)$$

To obtain the improved rate equations of TDFA, an analysis of a four level energy system is discussed. Fig. 2 shows the energy level diagram of trivalent thulium ion in fluoride glass. The main transition used for S-band amplification is from the 3H4 to 3F4 energy levels. This amplification is made possible by a multistep pumping via excited state absorption (ESA) [21], which forms a population inversion between 3H4 and 3F4 levels. When the TDF is pumped with 1050nm laser, the ground state ions in the 3H6 energy level can be excited to the 3H5 energy level and then relaxed to the 3F4 energy level by non-radiative decay. The 1050nm is the most efficient wavelength for single-wavelength pumped TDFAs [22]. The impact 1050nm diode laser technology for the realization of a compact TDFA module is considered [23] for TDFA. In the rate equation models, the variables n0, n1, n2 and n3 are used to represent population density in the 3H6, 3F4, 3H5 and 3H4 energy levels respectively. The four population states of Tm+3 are state 0 with population density of n0, the state 1 with population density of n1, state 2 with population density of n2 and excited state 3 with population density of n3. The state 1 and state 2 are related with signal frequency and state 3 is related with pump frequency. Let P03 be the pumping rate from state 0 to excited state 3, P30 and P31 be the stimulated emission rate from excited state 3 to state 0 and state 1 respectively. It is assume that P30 is not considered as an important transition. There are two types of transitions that have been taken place from excited state 3, one is radiative transition and other is non-radiative transition. The radiative transition from excited state is further of two types i.e. state 1 and upto state 0 i.e. A31(r) and A30(r) respectively. It is also considered that the transition is mainly non- radiative, which implies that non-radiative transition (A31(nr)) » radiative transition (A31(r), A30(r)). Let the rate of stimulated absorption and emission be S01 and S10 respectively. The rates of spontaneous emission from state 1 are also radiative and non-radiative in nature, at this level radiative transition (A10(r)) » non-radiative transition (A10(nr)). The non-radiative transition from excited state 3 and radiative transition from state 1 are considered as n3/τ' and n1/τ respectively, where τ' and τ are the respective transition rates.

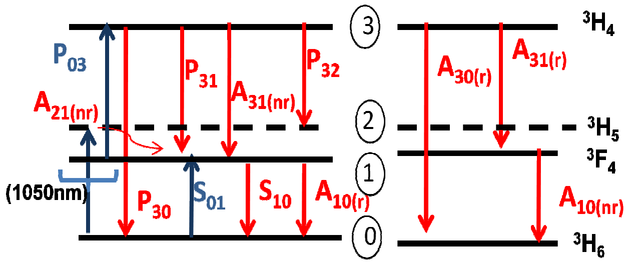

Fig. 2 Energy Transitions in a Four Level TDFA

So, the improved rate equations of the four states for the proposed model of TDFA are given in (2).

$$\frac{\delta n_0}{\delta t} = \left(-P_{03}\ n_0\ - S_{01}\ n_0\ + S_{10}\ n_1 + \frac{n_1}{\tau} + P_{30}n_3 + \frac{n_3}{\tau'}\right)$$

$$\frac{\delta n_1}{\delta t} = \left(S_{01}\ n_0\ - S_{10}\ n_1 - \frac{n_1}{\tau} + P_{31}n_3\right)$$

$$\frac{\delta n_2}{\delta t} = \left(-A_{(nr)21}\ n_2\ + P_{32}n_3\right)$$

$$\frac{\delta n_3}{\delta t} = \left(P_{03}\ n_0\ - P_{31}\ n_3 - P_{30}n_3 - \frac{n_3}{\tau'}\right) \quad (2)$$

These rate equations involve several assumptions. Firstly, it has been assumed that any population in the 3H5 level will relax rapidly to the 3F4 level in a time scale which is short in comparison to the other decay times involved; thus the presence of the 3H5 level has been ignored. Secondly, by representing the ETU process we have ignored any energy migration processes, which is justifiable since this process occurs on a much smaller time scale (~10-10s) [24]. Thirdly, it was assumed that ESA of the pump and signal photons can be ignored due to the relatively low ESA cross sections at the respective wavelengths. It has been estimated that the ESA cross section at the pump and signal wavelengths (1586 and 1800nm) were to be ~ 3×10-31 and ~ 0 m2, respectively [25]. Although there is a relatively large error associated with these values, it suggests that ESA does not play a significant role in the upconversion process at these wavelengths. Algorithms (I & II) describes the mathematical modeling of EDFA and TDFA respectively.

Algorithm I: Algorithm_EDFA

STEP I: Initialize n_g, n_m and n_e (Er^{+3} ion densities at ground, metastable and excited states),A(area), L(length of Fiber),Pp &Ps (Pump and Signal Power),λp &λs (Pump and Signal Wavelength)
STEP II: ng, nm, ne and L= variable
STEP III: Calculate ion of Er+3 in metastable state and length of EDF
STEP IV: Calculate Gain with respect to Length of Fiber
STEP V: Calculate Optimum Length of fiber for maximum gain
STEP VI: Plot gain for optimum length of EDF w.r.t.wavength
STEP VII: Goal Achieved

Algorithm II: Algorithm_TDFA

STEP I: Initialize n0, n1 and n3 (Tm+3 ion densities at ground, metastable and excied states),doping concentration, I/P power, number of channels, spacing, A(area), L(length of Fiber),Pp &Ps (Pump and Signal Power),λp &λs (Pump and Signal Wavelength),ASE power and I/P signal
STEP II: n1, n1 , n3,L and doping concentration = variable
STEP III: Calculate optimum doping concentration for peak gain
STEP IV Calculate length for peak gain (with ASE)
STEP VI: Calculate optimum length
STEP VII: Plot gain for optimum length of TDF w.r.t.wavength
STEP VIII: Goal Achieved

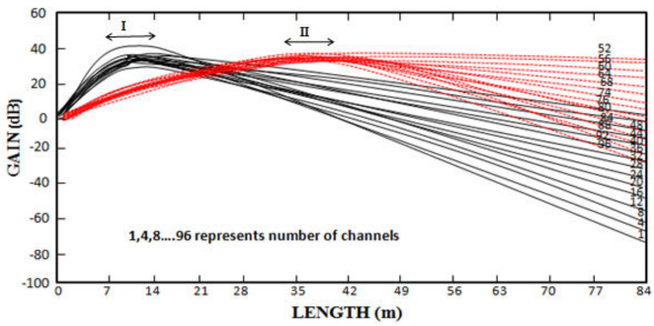

Fig. 3 Variation of Gain of EDFA versus Length of EDF for 1479nm to 1555nm Range

As per Fig. 3 and Algorithm I, clarifies that increase in the amplifier length results in an increase of its gain when there is a suitable pumping power in accordance with the increase of the length [26]. In other words, the increase in the amplifier length causes an increase in the number of carriers at the ground level (doping increase). Since in the present work the optimal length of EDF is to be found, so a graph is plotted for gain of EDFA versus wavelength for different lengths of EDF as shown in Fig. 4 EDF are taken from 4m to 14m.

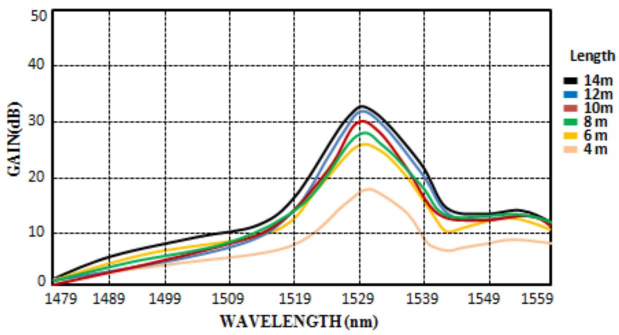

Fig. 4 Gain of EDFA versus wavelength for different lengths

This research is an attempt to increase the gain bandwidth and to reduce the noise figure of fiber amplifier by modeling hybrid Thulium and Erbium doped fiber amplifier for DWDM system. The spacing of 0.8nm is chosen as per ITU-T Recommendation G.694.1, which is specifically for DWDM system. There is one efficient method of utilizing fiber amplifiers for optimum utilization of available fiber bandwidth i.e. by way of using various combinations of optical amplifiers in different wavelength ranges. The amplifiers can be connected either in parallel or in series. The amplifiers connected in series have relatively wide gain band, because they do not require couplers. So, in this work series combination of hybrid amplifiers has been proposed.

III. Implementing HTE for DWDM System

In this paper, a HTE has been demonstrated as shown in Fig. 5, the configuration HTE means the hybrid amplifier in which TDFA is in first stage and EDFA is in second stage.

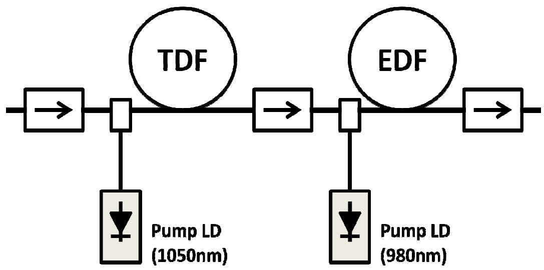

Fig. 5 Schematic arrangement of HTE

The main goal of the research in this chapter is the performance modeling of HTE for DWDM system. A mathematical model and Algorithm of HTE configuration is specially designed after considering all major impairments.

Algorithm III: Algorithm_HTE

STEP I: Initialize mathematical models of TDFA & EDFA
STEP II: Mathematical modeling of the cascaded configuration of TDFA & EDFA for DWDM channels for 1479-1555nm
STEP III: Calculate gain, NF of HTE
STEP IV: Goal achieved

IV. Conclusion

In this paper, Mathematical modeling of HTE has been implemented by considering all major impairments. The aim of the research is first to find out the optimum lengths of EDF and TDF fiber. Then using those optimum lengths of EDF and TDF, HTE has been modeled. This HTE configuration is the implemented for DWDM system for enhancing the broadening of gain for 1479nm-1555nm wavelength range as shown in Fig. 6.

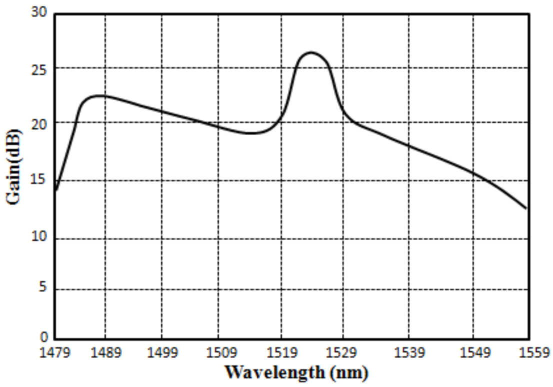

Fig. 6 Gain versus Wavelength of HTE

It has been depicted from Fig. 6 that the gain of 26dB is achieved in the wide wavelength region from 1479nm to 1555nm, when optimum lengths of TDF and EDF of 10m and 6m were used. When TDF length is increased, then wavelength became narrower with high gain peak. This was due to the fact that gains peak shift in the first stage TDFA of more than 10m length.

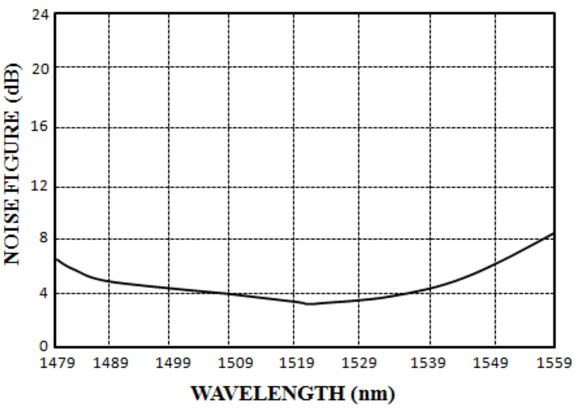

Fig. 7 Noise Figure versus Wavelength of HTE

The NF of HTE became worse as TDF lengths increased. With this cascaded configuration low NF is achieved in 1479nm to 1555nm wavelength region as shown in Fig.7.

References

[1] Olsson N.A., “Lightwave Systems with Optical Amplifiers”, J. Lightwave Tech. Vol. 7, July 1989.

[2] Khalid A.S. et.al “Theoretical Analysis of a Double Sstage EDFA” ICCCE 2010, May 2010, ISBN: 978-1-4244-6235-3.

[3] Keiser G., “Optical Fiber Communications”, 4th Edition, TMH.

[4] Mynbaev D. K., L. L. Schiner’ “Fiber Optics Communications Technology”, Pearson Education, Inc., 2003.

[5] Jung et.al “A Band Separated , Bidirectional Amplifier based ED_Bisumath Fiber for Long Reach Hybrid DWDM-TDM Passive Optical N/W” Journal of Optical Commun. N/W, pp165-172, Mar 2012.

[6] Lee Y.W., Nilsson J., Hwang S. T., and Kim S. J., “Experimental Characterization of a Dynamically Gain-Flattened Erbium- Doped Fiber Amplifier”, IEEE Photonics Technology Letters, Vol. 8, December 1996.

[7] Sun Y., Member, Judkins J. B., Srivastava A. K., Garrett A. K., Zyskind J. L., Sulhoff J. W. , Wolf C. , Derosier R. M. , Gnauck A. H. , Tkach R. W. , Zhou J., Espindola R. P., Vengsarkar A. M. , and Chraplyvy A. R., “Transmission of 32- WDM 10-Gb/s Channels Over 640 km Using Broad-Band, Gain-Flattened Erbium-Doped Silica Fiber Amplifiers”, IEEE Photonics Technology Letters, Vol. 9, December 1997.

[8] Sohn I.B., Baek J.G., Lee N.K., Kwon H.W. and Song J.W., “Gain flattened and improved EDFA using micro bending long-period fiber gratings”, Electronics Letters, Vol. 38, October 2002.

[9] Kim H.S., Yun S.H., Kim H.K., Park N., and Kim B.Y., “Actively Gain-Flattened Erbium-Doped Fiber Amplifier Over 35 nm by Using All-Fiber Acousto-optic Tunable Filters”, IEEE Photonics Technology Letters, Vol. 10, June 1998.

[10] Lu Y.B. and Chu P. L., “Gain Flattening by Using Dual-Core Fiber in Erbium-Doped Fiber Amplifier”, IEEE Photonics Technology Letters, Vol. 12, December 2000.

[11] Lobo A.E., Besley J.A., and Sterke M.C.D., “Gain Flattening Filter Design Using Rotationally Symmetric Crossed Gratings”, J. Lightwave Technol., Vol. 21, 2003.

[12] Kawai S., Masuda H., Suzuki K.I., Aida K., “Wide Bandwidth and Long Distance WDM Transmission Using Highly Gain Flattened Hybrid Amplifier”, IEEE Photonics Technology Letters, Vol. 11, July 1999.

[13] Kumar N., Shenoy M. R., and Pal B. P., “A Standard Fiber- Based Loop Mirror as a Gain-Flattening Filter for Erbium- Doped Fiber Amplifiers”, IEEE Photonics Technology Letters, Vol. 17, October 2005.

[14] Park S. Y., Kim H. K., Lyu G. Y., Lee H. J., Lee J. H., and Shin S.Y., “Accurate Control Of Output Power Level In Gain- Flattened EDFA With Low Noise Fig.”, ECOC 97, 22-25 September 1997, Conference Publication No. 448, IEEE, 1997.

[15] Sun Y., Sulhoff J.W., Srivastava A.K., Abramov A. , Strasser T., Wysocki P.F. , Pedrazzani J.R., Judkins J.B., Espindola R.P. ,C. Wolf J,.Zyskin L . , Vengsarkar A .M., and Zhou J. , “A Gain-Flattened Ultra Wide Band EDFA For High Capacity WDM” for OSC ECOC'98,20-24 September 1998, Madrid, Spain.

[16] Kaur I., Gupta N., “Increasing the Amplification Bandwidth of EDFA Using A Cascaded Raman –EDFA Configuration”, at IIT, Delhi, Photonics 2008, sponsored by IEEE; pp.284, Dec 13th -17th 2008.

[17] Kaur I., Gupta N., “Enhancing the Performance of WDM Systems By Using TFF in Hybrid Amplifiers”, 2010 IEEE 2nd International Advance Computing Conference, Patiala,India, pp 106-109, Feb 2010.

[18] P/Peterka et.al “ Thuluium Doped Silica Fiber with Enhanced 3H4 level Lifetime for fiber Laser & amplifiers” ICOP2012,pp56-60, Penag, ISBN: 978-1-4673-1463-3.

[19] T.Kasamatsu, Y. Yano, T. Ono, “Gain- shifted dual wavelength pumped thulium- doped fiber amplifier for WDM signal in the 1.48-1.51 μm region” Photonics Technology Letters 13(1):31-33, 2001.

[20] S. Aozasa, H. Masuda, T. Sakamoto, K. Shikano, and M. Shimizu, “Gain shifted TDFA employing high concentration doping technique with high internal power conversion efficiency of 70%,” Electron. Lett., vol. 38, no. 8, pp. 361–363, Apr. 2002.

[21] S.Aozasa, T. Sakamoto, T. Kanamori, K. Hoshino and M. Shimizu, “Gain-shifted thulium –doped fiber amplifiers employing novel high concentration doping technique” Electronics Letters, 36(5) 418-419, 2000.

[22] Seo Yeon Park, Hyang Kyun Kim, Gap Yeol Lyu, Sun Mo Kang and Sang Yung Shin, “ Dynamic Gain and Output Power Control in a Gain-Flattened EDFA”, IEEE Photonics Technology Letters, Vol. 10, No. 6, pp. 787-789, June1998.

[23] A. S. L. Gomes, M. T. Carvalho and M. L. Sundheimer, “Comparison of distributed gain in twe dual-wavelength pumping schemes for Thulium-doped fiber amplifiers”, Electron. Lett., vol. 39, no. 8, pp. 647-648, Apr. 2003.
[24] B. Bourliaguet et al, “Thulium-doped fiber amplifier using 1055 nm laser diode pumping configuration”, Electron. Lett., vol. 38, no. 10, pp. 447–448, 2002.
[25] P. Peterka, B. Faure, W. Blanc, M. Karasek, B. Dussardier, Opt. Quantum Electron. 36 (2004) 201
[26] Kaur Inderpreet, Gupta Neena , “Optimization of Fiber Length for EDFA to Enhance The Channel Capacity DWDM System” IEEE International Symposium on Instrumentation & Measurement, Sensor Network and Automation (IMSNA), 2012 ,Volume:1 pp7-10, China. Digital Object Identifier: 10.1109/MSNA.2012.6324504 .